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Analysis

Assessing Impacts From Climate Change on Local Social-ecological Systems in Contexts Where Information is Lacking: An Expert Elicitation in the Bolivian Altiplano☆

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ABSTRACT

Assessment of the expected impacts from climate change is an essential input for agencies engaged in fostering adaptation of local social-ecological systems. However, data is seldom available at the required scale. This study overcomes this hurdle by gathering data via an expert elicitation protocol. We report experts' judgements about two topics: i) the impacts from climate change on crop yields in three communities located in the Bolivian Altiplano; and ii) the effectiveness of specific irrigation techniques in mitigating the impacts from climate change in the communities under study. Our gathered data allow us to document heterogeneity of expected impacts across communities –with one community expected to experience an increase in yields under wet climate change scenarios. Experts judge irrigation as an effective mitigation tool under most of the dry climate change scenarios presented to them. We believe that our data collection strategy represents a promising decision support tool for a wide range of public policy issues. Particularly, when monetary and time constraints converge with the lack of scientific information. In addition, the information gathered with this methodology can be incorporated into participatory methodologies gathering information from local social-ecological systems.

1. Introduction

Climate change has been characterized as local in its causes and global in its impacts (Shaw et al., 2009). Unfortunately, documentation of the impacts from climate change has mostly focused on the global scale. This focus is not surprising given that data at local scale are frequently of poor quality and/or seldom available.

There is a pressing need to collect information at local scale. This is so because if the causes of climate change are local, the strategies to build resilience may be found at the local scale as well. And this has been the case. For instance, Mistry et al. (2016) has successfully implemented a participatory strategy that helps communities in the identification of local best practices for social-ecological sustainability. Also, local information is essential in the documentation of the expected heterogeneity of climate change impacts (Vincent, 2007) –allowing, for instance, the identification of local social-ecological systems[1] potentially benefiting from climate change.

National and international agencies have recently increased their efforts to gather data at local scales. For instance, the Inter-American Development Bank has stated its intention of incorporating measures of local adaptive capacity in evaluations of community projects involving

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[1] The term *social-ecological system* is used to emphasize “the integrated concept of humans in nature and to stress that the delineation between social and ecological systems is artificial and arbitrary” (Folke et al., 2005, p. 443).

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water and sanitation, technology innovation, and irrigation (IADB, 2013). Also, the Paris Agreement, signed in December 2015 in the COP21 meeting, is expected to increase the demand for local information given that the developed countries have committed to increase funds to avert local damages provoked by climate change (UNFCCC, 2015, p. 26).

This study explores the feasibility of collecting local data via a protocol that gathers the opinion from experts on how climate change will impact local social-ecological systems. Treating expert judgement as a type of scientific data that fits into an empirical research strategy is the departure point of the expert elicitation literature (Bolger and Rowe, 2015; Cooke and Goossens, 2000). For instance, Vaissière et al. (2013) incorporate the opinion of experts in a methodology that compares maintenance costs associated with compensating the damage of ecosystem services. They request experts to quantify the contribution of habitats and species to the production of an ecosystem service.

This study delivers two pieces of information. The first piece reflects the experts' judgements about the climate change impacts on crop yields in communities located in the Bolivian Altiplano. We have selected this region because it illustrates that the evidence about effects from climate change in the Altiplano region has not translated into a data gathering strategy that may support the design of policies tackling the expected impacts to the local social-ecological systems (see World Bank, 2010).

Informing policy makers about the expected impacts from climate change is not enough. They also need information about the effectiveness of potential mitigation actions. Thus, the second piece of information reported by this study captures experts' judgements on whether specific irrigation techniques are expected to be effective in mitigating the effects from climate change. We deem irrigation as a potential mitigation tool because it provides protection against precipitation volatility associated with climate change (Lybbert and Sumner, 2012; Vermeulen et al., 2012). To gather data valuable to policy makers, our irrigation scenarios have been designed to resemble irrigation projects implemented through the Bolivian National Irrigation Program.

The rest of this paper is structured as follows. Section 2 justifies our focus on communities located in the Bolivian Altiplano. Section 3 describes our methodology. Section 4 reports the opinions of our experts. Section 5 presents a methodological discussion. Section 6 presents our conclusions.

2. Case Studies

The Bolivian Altiplano illustrates the problem of data availability regarding impacts from climate change at the local scale. On one hand, there is enough evidence to argue that climate change is already impacting the Bolivian Altiplano via extreme weather events and higher weather variability (World Bank, 2010). For instance, extreme weather events such as El Niño provokes rainfall decline in the Altiplano (Andersen and Mamani, 2009). In 2010, a more severe drought affected the area due to the shortening of the rain season (MMAAB, 2009). An unprecedented hailstorm in 2002 caused a U.S. $70 million damage and droughts with a bigger-than-usual influence area. These events are becoming repetitive and persistent, intensifying or triggering socioeconomic phenomena such as migration from the countryside to the cities.

On the other hand, despite the documented evidence of the effects of climate change on the Bolivian Altiplano, the greatest challenge for the social-ecological systems in this region is the uncertainty about the geographical distribution of such impacts (World Bank, 2010). Due to the unique topographic conditions of the Bolivian Altiplano, researchers expect a large heterogeneity in the effects from climate change on local social-ecological systems –with chances that some systems may benefit from climate change and others may face negative impacts.

Thus, as a first step to design a strategy to face climate change, policy makers need to be informed with estimates of the expected impacts not only at the regional scale but also at the local scale –with emphasis on the identification of the local systems that may gain and the local systems that may be damaged by climate change. However, information at a local scale is seldom available for this region (World Bank, 2010).

In this context, we implement our expert elicitation methodology in the Bolivian Altiplano. Three Altiplano communities are taken as case studies. As illustrated in Fig. 1, Suriri-Capiri, Pasacunta-Qollpacanta, and Peñas Kerani are part of, respectively, the municipality of Tiwanaku, the municipality of Calacoto, and the municipality of Batallas. The three communities are in the administrative department of La Paz –which is part of the dry Altiplano. In this sub-region, low temperatures, high variability of temperatures, low humidity, low rainfall and recurrent and long periods of drought impose severe conditions to crop and livestock production (World Bank, 2010).

The three communities under study are useful to gain insights on how effective irrigation may be at mitigating the impacts from climate change. These communities have benefited from irrigation projects financed by PRONAREC –the National Irrigation Program with a Watershed Approach (IDB, 2008). Thus, the irrigation scenarios included in our protocol closely resemble the projects financed by PRONAREC – which allows us to gain insights of public policy relevance.

3. Methodology

We collect data through an expert elicitation (EE) protocol. EE is a structured process that collects scientific and technical judgements from experts (Morgan, 2014; Bosetti et al., 2016). EE is deemed a useful piece of empirical research, particularly when other empirical data is expensive, limited or unreliable (Bolger and Rowe, 2015; James et al., 2010).

Bosetti et al. (2016) describes EE in eight steps –these steps are executed in an iterative manner and thus a practitioner may return to a specific step several times. In the first step, an EE describes the objective and mode of the elicitation. The definition of the goal includes an unambiguous description of the metric that experts are requested to use when reporting the parameter of interest. The elicitation mode ranges from face-to-face interviews to protocols that can be self-administered via a web-based platform –importantly, the selection of the elicitation mode is not without trade-offs (see Baker et al., 2014; Verdolini et al., 2015).

In the second step of an EE, the practitioner defines the type of expertise needed and identifies the individuals with such expertise. In the third step, the type of expertise and the goal of the EE are taken into consideration to decide the format of the elicitation question. In the fourth step, experts are provided with background material and trained in the rationale behind the elicitation question. This step may be carried out in advance to the implementation of the protocol or as a preliminary step during the elicitation. In the fifth step, the EE protocol is tuned by piloting parts or the entire protocol –making sure that the metric of interest is clear to the experts and that, if it is the case, the hypothetical scenarios are precisely described.

The sixth step consists in gathering the data via the elicitation protocol. The statistical analysis of the gathered data is the seventh step of an EE. The final element is the reporting of the experts' opinions (see Bosetti et al. (2016) for details about these steps).

The rest of this section provides the specifics of the EE protocol implemented in this paper.

3.1. Expert Elicitation Protocol

3.1.1. Goal

The goal of our EE protocol is twofold. First, it collects and summarizes the opinion of experts about the expected impacts from climate change on potato yields in three communities located in the Bolivian Altiplano. Second, it collects and summarizes the opinion of experts with respect to whether irrigation is an effective tool to mitigate the changes in potato yields in the communities under study.

Potato has been chosen as the crop of interest because it is the most important crop in the Bolivian Altiplano (World Bank, 2010) –both in

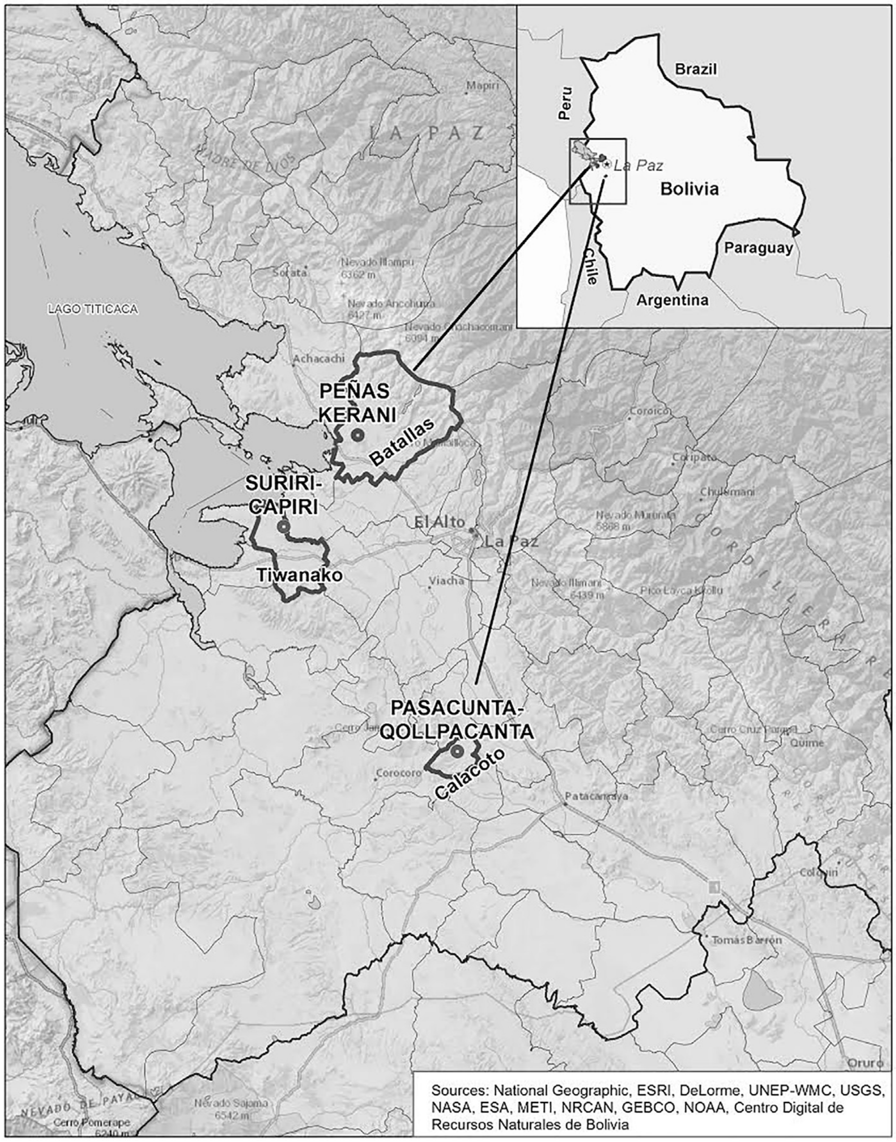

Fig. 1. Location of communities under study.

terms of percentage of family income coming from this crop (50%–80%), and hectares dedicated to this crop (half of the crop surface).

3.1.2. Our Experts

The selection of experts is key to our methodology. For purposes of this study, an expert is an individual that has worked at and/or studied the local social-ecological systems in the Bolivian Altiplano. This individual is expected to know the factors that impact crop yields –with emphasis on potato. Ideally, experts have developed a mental model that maps variations in precipitation and temperature into variations in potato yields. Under this description, a potential expert may work directly with communities in the Bolivian Altiplano, or may have worked with them earlier and his/her current professional activities are such that his/her information about these communities is regularly updated.

A list of 21 experts was put together in January 2014. This lists was initiated with the suggestions from Agronomists Carlos Rodriguez –Director of PRONAREC in 2014—, and Corina Apaza –hired to assist the research team in the process of designing and implementing the elicitation protocol, and recruiting the experts. Experts contacted at this stage were also invited to suggest the names of additional experts.

An email invitation was sent to all 21 experts. Eighteen of them replied positively. These 18 experts were personally visited by the leading co-author of this paper during the third week of January 2014. During these visits, experts were informed about the goals and structure of the expert elicitation protocol. These 18 experts were invited to answer the final version of the protocol during the second week of July 2014 at La Paz, Bolivia. Twelve of them were available to answer the protocol.

Table 1 describes the professional activities and expertise of the 12 experts that responded our protocol. All 12 experts are agronomists.

Table 1
Experts participating in the elicitation protocol.

Expert	Sector	Area of expertise
Giovanna Salinas Murillo	Government	Climate change
Rosa Zavala	Government	Climate change
Octavio Boris Arias Irusta	Government	Risk analysis
Lucio R. Tito Villca	Academy/government	Risk analysis
Israel Romero Salazar	Technician	In field
Eliana Espejo Ticona	Technician	In field
Victor Cortez Limachi	Technician	In field
Manuel Chino Velasquez	Technician	In field
Carlos Hector Escobar Ramos	Technician	In field
Emilio Garcia Apaza	Academy	Agronomy/climate change
Eleodoro Baldiviezo Estrada	NGO	In field
Maria Quispe	NGO	In field

Two experts work in a governmental agency dealing with climate change challenges. Two experts work in a governmental agency dealing with risk analysis –one of these experts is an academic researcher that has published books describing the agronomic conditions of the Altiplano. The main activities of these four experts do not involve regular visits to the communities in the Altiplano. However, they did work in the area of interest earlier in their professional career.

The other eight experts were working with several communities in the Altiplano at the time they answered our protocol. Five experts are technicians directly working at the communities. One expert is an academic researcher with focus on the Altiplano communities. Two experts work for an NGO that focuses on improving productivity in the Altiplano.

3.1.3. Elicitation Mode, and Implementation

Experts' judgements were elicited in three sessions – two workshops attended by 5 and 6 experts, respectively, and one personal interview. All three sessions had an identical structure, and took place during the second week of July 2014 at La Paz, Bolivia. During the first 30 min, experts were remained of the EE protocol's goal, and the context in which the study was carried out. During the second half-hour, the facilitator explained the rationale behind the elicitation questions, and experts were faced to examples of the EE questions. During the last 2 h of the session, experts answered the EE protocol.

Experts were encouraged to exchange points of view during the first hour of the workshop. Also, they were encouraged to answer the protocol taking into consideration what had been discussed but without consulting to each other during the last 2 h of the workshop.

3.1.4. Farming Conditions, Average Weather Conditions, and Irrigation Scenarios

Experts cannot provide unconditional judgements –i.e. if an expert is asked about average yields, he/she will first want to know the conditions under which he/she is supposed to forecast the yields. Keeping the social system fixed, a non-exhaustive list of the ecological factors impacting crop yields include the type of soil, the cropping season, and the average and variation of the temperature and the precipitation. Also, the conditions of the previous cropping season matter when forecasting expected yields.

Indeed, elements of the social system matter as well because social-ecological systems are complex and include reciprocal feedbacks (Folke et al., 2005; Ostrom, 2009). A non-exhaustive list of social factor impacting the crop yields include whether farming activities are the farmer's main source of income, and local governance.

Thus, the research team extensively discussed how to describe the agronomical scenario under which experts are requested to report expected yields. In this process, we received the assistance of Agronomist Corina Apaza –who has worked with and at communities in the Bolivian Altiplano. In addition, an expert answering a pilot protocol was also consulted on the adequacy of the agronomical scenario. The final agronomical scenario aims to be understandable and simple enough, and to include the most essential factors impacting yields.

Six farming factors are included in our agronomical scenario: i) the variety of potato; ii) the type of soil; iii) whether chemical fertilizer is used; iv) whether pest control measures are implemented; v) cropping season; and vi) irrigation technique.

The farming conditions have been described to the experts as follows:

> *Consider a community situated in the Altiplano. This community belongs to the* ***municipality***, ***province***, *in the administrative department of La Paz. Consider a farmer in this community. This farmer grows* ***variety of potato***, *in his/her* <u>*private one-hectare*</u> *parcel which is composed primarily of* ***soil type***. *He/she uses* ***irrigation technique***, <u>*chemical fertilizers*</u>, *and* <u>*no pest control strategies*</u>. *Preparation of lands is carried out from* <u>*August to September*</u>. *Planting is carried out from* <u>*mid-October to mid-November*</u>. *Harvest is expected from* <u>*March to April*</u>.

Table 2
Farming conditions and irrigation scenarios in communities under study.

Characteristics	Communities under study		
	Suriri-Capiri	Pasacunta-Qollpacanta	Peñas Kerani
Municipality	Tiwanaku	Calacoto	Batallas
Province	Ingavi	Pacajes	Los Andes
Potato variety	Huaycha	Luki	Huaycha
Soil type	Clay loam	Sandy loam	Clay loam
Irrigation 1	No irrigation	No irrigation	No irrigation
Irrigation 2	Stone-lined channels	Stone-lined channels	Open channel

Notice that the community of reference is not named but we do specify the municipality and province where each community is located –Table 2 lists this information. This strategy is meant to encourage experts to keep in mind factors that are similar among communities located within a municipality but vary for communities located in different municipalities –in econometric jargon, this strategy encourages the expert to control for municipality fixed effects. This type of factors cannot be exhaustively listed, and their relevance may differ depending on the expert. Examples of such factors may include the distance to Titicaca lake, the distance to the La Paz, capital of Bolivia, etc.

Table 2 lists the varieties of potato and the soil types for each community. Potato has adapted very well to the climate condition in the Altiplano –in particular, the Huaycha and Luki varieties. The Huaycha variety grows well in clay loam soil which is the most common soil in Suriri-Capiri and Peñas Kerani. The Luki variety grows well in sandy loam soil and is particularly resistant to frosts which are recurrent in Pasacunta-Qollpacanta.

Table 2 reports the irrigation scenarios considered for each community –no irrigation and a given irrigation technique. The irrigation technique at each community corresponds to the one financed by PRONAREC –water distribution through open channel in Peñas Kerani, and stone-lined channels in Pasacunta-Qollpacanta and Suriri-Capiri.

Three factors are kept fixed across the three communities: i) type of fertilizer is described as chemical fertilizer; ii) no pest control measures are implemented; and iii) the cropping season runs from August to April. These features are representative of communities in the Altiplano.

Together with the farming conditions, experts are informed about the average precipitation/temperature conditions for the 1990–2013 period. Table 3 reports these conditions for each community. The average values correspond to the observed average monthly values from October to February. Weather conditions during these months are essential for germination and development of potato in the Bolivian

Table 3
Average precipitation/temperature conditions (from 1990 to2013)[a].

Variables	Oct.	Nov.	Dec.	Jan.	Feb.
Suriri-Capiri					
Precipitation (mm)	25.60	43.00	69.40	108.90	85.20
Temperature (°C)	9.10	10.10	10.10	10.10	9.90
Pasacunta-Qollpacanta					
Precipitation (mm)	20.80	24.00	80.00	123.60	88.70
Temperature (°C)	8.50	9.90	10.80	10.60	10.50
Peñas-Kerani					
Precipitation (mm)	36.10	45.70	113.40	125.20	95.90
Temperature (°C)	8.80	9.50	9.80	9.50	9.40

[a] Manually downloaded from SENAMHI at http://www.senamhi.gob.bo/meteorologia/formularioboletinmensual.php.

Altiplano. Temperature and precipitation values are obtained from the closest climatological stations to the communities under study. Information has been downloaded manually from the official webpage of the Bolivian agency in charge of measuring weather conditions.

3.1.5. Climate Change Scenarios

Climate change, in this study, is characterized through four precipitation/temperature scenarios. These scenarios aim to capture weather conditions likely to hold under climate change conditions during the cropping season of interest. To better convey the type of weather conditions we aim to represent, we label the precipitation/temperature scenarios as *dry* or *wet* –although scenarios are presented unlabeled to the experts.

Two documents have been consulted to design the climate change scenarios. The first one is an *official* reference in the sense that it has been endorsed by the Bolivian government through its Ministry of Environment. This Ministry has issued official forecasts of climate change scenarios for the years 2001 to 2030, and 2071 to 2100 (MMAAB, 2009). This official reference reports that the Altiplano is expected to face an increase in temperature ranging from 0.5 °C to 1.5 °C by 2030; and annual precipitation is expected to remain the same or decrease by 15 mm.

The second consulted document is a World Bank report on the consequences of climate change (World Bank, 2010). This report suggests two climate change scenarios are plausible in 2030. A *wet* scenario would bring an increase of 1.55 °C in average temperature and a 22% increase in the annual mean precipitation. A *dry* scenario would imply an increase in temperature by 2.41 °C and a 19% decrease in precipitation.

The official scenario somehow contains the two World Bank scenarios. With respect to temperature, the official scenario assumes a value close to the maximum temperature of the wet World Bank scenario. With respect to precipitation, the range of variation in the official scenario includes the values of the dry World Bank scenario. Consequently, the scenarios designed in this study aim to capture the intersection of both the official and the World Bank reports.

Table 4 reports the climate change scenarios designed for each community under study. The four scenarios were unlabeled when presented to the experts. However, for exposition purposes, Table 4 labels them as *dry observed* (*DO*), *wet observed* (*WO*), *wet climate change* (*WCC*), and *dry climate change* (*DCC*).

On one hand, the DO and WO scenarios together capture the conditions suggested by the official scenario. The DO and WO scenarios have recently occurred –they have been chosen among the years with available measures near each community. They are labeled as dry or wet with respect to the average conditions presented in Table 3. For instance, under the DO scenario for Suriri-Capiri, precipitations from November to January are lower than in the average scenario −22.90 mm, 18.50 mm, and 82.50 mm versus 43.00 mm, 69.40 mm, and 108.90 mm. Also, during the same months, average temperatures in the DO scenario are lower in comparison to the average scenario −9.10 °C, 10.10 °C, and 9.80 °C versus 10.10 °C, 10.10 °C and 10.10 °C. A similar reasoning is behind the DO and WO scenarios for each community.

On the other hand, the DCC and WCC scenarios resemble the wet and dry World Bank scenarios. The values for the DCC and WCC are hypothetical –i.e. they have not occurred but can plausibly occur— and have been calculated with respect to the average scenarios listed in Table 3. The WCC scenario implies an increase in monthly average temperature of 1.7 °C, and an increase of 28% in monthly precipitation. The DCC scenario implies an increase in temperature of 2.5 °C and a reduction of 20% in precipitation.

3.1.6. Elicitation Questions

Experts' judgements are elicited through a five-step procedure –which is depicted in Fig. 2. In the first step, the agronomical scenario is presented to the experts. This scenario contains a description of the farming conditions and the average precipitation and temperature conditions (see Section 3.1.4). Experts are told to keep this agronomical scenario in mind through the elicitation procedure.

In the second step, an irrigation scenario is presented to the experts. All experts are presented to two irrigation scenarios for each community under study. In a first round of elicitation questions, the agronomical scenario is presented together with a no irrigation scenario. In a second round of elicitation questions, the same agronomical scenario is

Table 4
Precipitation and temperature conditions in climate change scenarios.

Scenario	Variables	Oct.	Nov.	Dec.	Jan.	Feb.
Suriri-Capiri						
Dry observed (1999)	Precipitation (mm)	38.80	22.90	18.50	82.50	88.50
	Temperature (°C)	8.80	9.10	10.10	9.80	9.50
Wet observed (2013)	Precipitation (mm)	20.50	10.50	129.50	127.70	92.50
	Temperature (°C)	9.10	10.60	10.20	9.50	9.70
Dry climate change	Precipitation (mm)	18.08	29.04	62.64	78.88	64.56
	Temperature (°C)	13.00	14.00	14.00	13.80	13.60
Wet climate change	Precipitation (mm)	28.93	46.46	100.22	126.21	103.30
	Temperature (°C)	11.20	12.20	12.20	12.00	11.80
Pasacunta-Qollpacanta						
Dry observed (1999)	Precipitation (mm)	2.50	5.50	77.80	115.50	74.50
	Temperature (°C)	8.20	9.70	11.20	11.10	11.30
Wet observed (2013)	Precipitation (mm)	64.00	25.00	78.50	79.90	43.10
	Temperature (°C)	8.70	10.30	10.30	10.70	9.60
Dry climate change	Precipitation (mm)	15.36	22.32	74.40	112.56	71.20
	Temperature (°C)	12.20	14.00	14.70	14.20	14.20
Wet climate change	Precipitation (mm)	24.96	36.27	120.90	182.91	115.70
	Temperature (°C)	10.70	12.50	13.20	12.70	12.70
Peñas Kerani						
Dry observed (1999)	Precipitation (mm)	20.00	32.00	51.90	92.60	73.00
	Temperature (°C)	8.80	8.70	8.10	7.40	9.80
Wet observed (2013)	Precipitation (mm)	47.80	60.30	129.10	105.80	68.00
	Temperature (°C)	9.30	10.40	10.90	10.20	10.40
Dry climate change	Precipitation (mm)	23.92	42.08	111.68	89.04	84.64
	Temperature (°C)	12.80	13.70	13.80	13.40	13.20
Wet climate change	Precipitation (mm)	38.87	68.38	181.48	144.69	137.54
	Temperature (°C)	11.30	12.20	12.30	11.90	11.70

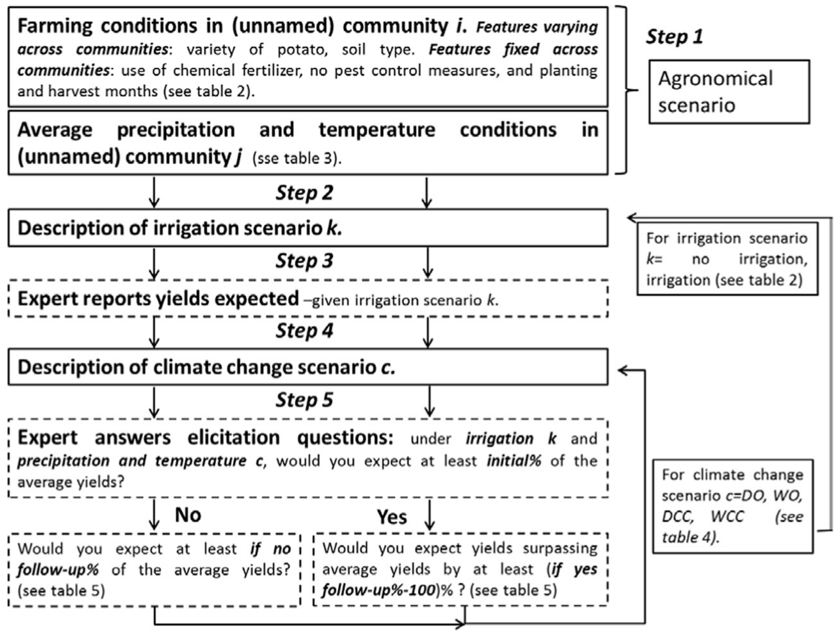

Fig. 2. Schematic description of the elicitation procedure.

presented together with an irrigation technique scenario that varies by community (see Section 3.1.4).

In the third step, experts report the average potato yields they expect under the irrigation and agronomical scenarios described in step 1 and step 2.

In step 4, a climate change scenario is presented to the experts. This scenario is described in terms of precipitation and temperature conditions expected to hold during the cropping season. All experts are presented to four climate change scenarios for each community under study (see Section 3.1.5). These scenarios are unlabeled –i.e. the expert does not receive information on whether the weather conditions have been observed or are hypothetical.

In step 5, experts report their expectations about the potato yields attainable under the climate change scenario presented in step 4. Experts are asked to keep in mind the irrigation scenario presented in step 2, and the agronomical scenario described in step 1.

Experts answer in a dichotomous manner to the elicitation questions in step 5. That is, experts answer either yes or no to the following question:

1. *Under this scenario, would you expect at least* ***initial %*** *of the average yields [reported by the expert in step 3]?*

If the answer to question (1) is no, then a follow-up question decreases the percentage presented to the expert:

2a. *Would you expect at least* ***if not follow-up %*** *of the average yields [reported by the expert in step 3]?*

If the answer to question (1) is yes, a follow-up question increases the percentage of presented to the expert:

2b. *Would you expect yields to surpass average yields [reported by the expert in step 3] by at least* ***(if yes follow-up %-100)%****?*

Notice that the elicitation questions (1), (2a) and (2b) use the average value reported in step 3 as a pivot value. That is, the expert judges whether yields feasibly will be lower or higher than yields he/she reported under average precipitation and temperature conditions –and answers with a yes or a no.

Table 5 reports initial and follow up percentages –i.e. *initial %*, *if no follow-up %*, and *if no follow-up %* in questions (1), (2a), and (2b). These percentages vary by irrigation and precipitation-temperature scenarios. These percentages do not vary across experts or communities under study but this is not a deterrent of the variation in the yields implied by the experts' dichotomous answers. First, the implied yields under climate change vary across experts regardless all experts answering to the same percentage changes because each expert uses his/her own average potato yields as reference. Also, the implied yields vary across communities because the reference average yields vary across communities.

The percentages reported in Table 5 have been designed to allow for the possibility that climate change either increase or decrease potato yields –i.e. either climate change may be beneficial or detrimental for a specific community. For instance, for the DO scenario in the first row of Table 5, the *if yes follow-up* percentage takes value 110% which implies that we are requesting from the expert to considerer whether dry conditions may increase potato yields by at least 10% with respect to the average yields. While this increase is unlikely under dry conditions, it may happen under wet conditions and that is why, for instance, the *initial* percentage for the WCC scenario is 110% (last row in Table 5). That is, we are asking from the expert to initially consider the plausibility that wet conditions may increase potato yields by at least 10%. If the answer is no, then we evaluate the possibility of a decrease of 30%. If the answer is yes, then we explore whether the expert may expect an increase of 40% in yields.

Table 5
Percentages presented to experts in elicitation question[a].

Scenario	No irrigation			Irrigation		
	Initial[b]	Follow up		Initial[b]	Follow up	
		If no[c]	If yes[d]		If no[c]	If yes[d]
Dry observed	80%	40%	110%	90%	70%	125%
Wet observed	90%	30%	115%	0%	60%	125%
Dry climate change	0%	50%	130%	105%	70%	140%
Wet climate change	110%	70%	140%	130%	80%	160%

[a] Step 3, substep 3 in Fig. 2.
[b] Initial question: Would you expect at least *initial %* of the average yields?
[c] If no: Would you expect at least *if no follow-up %* of the average yields?
[d] If yes: Would you expect yields surpass average yields by at least (*if yes follow-up % - 100*)%?

Also, by varying percentages across irrigation scenarios, we investigate whether yields are expected to be higher under irrigation and under climate change conditions. For instance, for the DO under no irrigation in the first row of Table 5, if the expert answers yes to the *initial* 80%, then the *if yes follow-up* question investigates whether a 10% increase in average yields is plausible. These percentages are higher for the irrigation scenario and the same DO scenario –90% and 25%, respectively— to allow for the possibility that irrigation is a mitigation tool.

Readers familiar with the non-market valuation literature may have noticed that our elicitation question heavily borrows from the double-bounded dichotomous question used in contingent valuation studies.[2] EE protocols usually request answers in the form of subjective probabilistic distributions (Morgan, 2014; Bosetti et al., 2016). However, our experts reported difficulty expressing their opinions directly in probability terms –which is not uncommon (see James et al., 2010). Thus, we decided to borrow the double-bounded dichotomous question –which proved to be more intuitive for our experts (see Section 5.1).

3.2. Statistical Approach to Aggregate Experts' Opinions

To summarize the opinions of our experts, we also borrow the maximum likelihood (ML) approach used in the contingent valuation literature to analyze data collected by a double-bounded dichotomous question (see Hanemann et al., 1991). Given a parametric distribution, the ML approach seeks the parameter values that maximize the probability of observing the gathered data.

To define the likelihood function of interest in this study, let W_{ejk} be the yields expected by expert e at community j under the average precipitation/temperature scenario and irrigation scenario k –step 3 in Fig. 2. Let Z^{bkc} be the percentage change presented by the elicitation questions –taking values reported in Table 5. The superscript $b = i, n, y$ denotes percentages presented to the expert in the elicitation questions: i refers to the *initial* percentage presented in question (1); n refers the percentage presented in question (2a) –the *if no follow-up* question—; and y refers to the percentage in question (2b) –the *if yes follow-up* question. The superscript $k = r, t$ denotes the percentages presented under each irrigation scenario: r refers to no irrigation, and t refers to the irrigation technique scenario. The superscript $c = do, wo, dcc, wcc$ denotes the climate change scenarios.

Then $W_{ejk}^{bc} = W_{ejk}(Z^{bkc}/100)$ are the yields implicit in the percentage changes presented by the elicitation questions. While the percentage changes Z^{bkc} are constant across communities and experts, the implicit yields W_{ejk}^{bc} vary across experts and communities because each expert's average yields (W_{ejk}) are used in the calculation of W_{ejk}^{bc}.

Finally, let $\overline{W}_{ejk}^{c}$ be the yields that expert e judges feasible to be observed at community j under irrigation scenario k and climate change scenario c. Then the likelihood function of our interest is defined as follows

$$\begin{aligned}\ln(\mathcal{L}) = \textstyle\sum_e \sum_j \sum_k \sum_c \Big\{ & d_j^{NN} \ \ln\left[Pr\left(\overline{W}_{ejk}^{c} < W_{ejk}^{nc}\right)\right] \\ & + \mathrm{d}_j^{YN} \ \ln\left[\Pr\left(W_{ejk}^{ic} < \overline{W}_{ejk}^{c} < W_{ejk}^{yc}\right)\right] \\ & + d_j^{NY} \ \ln\left[\Pr\left(W_{ejk}^{nc} < \overline{W}_{ejk}^{c} < W_{ejk}^{ic}\right)\right] \\ & + d_j^{YY} \ \ln\left[Pr\left(\overline{W}_{ejk}^{c} > W_{ejk}^{yc}\right)\right] \Big\},\end{aligned}$$

where $\mathcal{L}$ denotes the log of the likelihood function; d_j^{NN} takes value one if the expert has answered no to the initial elicitation question (1) and no to the if no follow-up question (2a), and zero otherwise; d_j^{YN}, d_j^{NY}, and d_j^{YY} are similarly defined for the sequences yes-no, no-yes and yes-yes.

Pr(.) refers to the probability that the event defined in parenthesis is considered a feasible event by the expert. For instance, $\Pr(W_{ejk}^{ic} < \overline{W}_{ejk}^{c} < W_{ejk}^{yc})$ refers to the probability that the yields judged feasible by expert e for community j under scenarios k and c (i.e. $\overline{W}_{ejk}^{c}$) fall in the range of values defined by the yields implicit in the initial question (1) and the if yes follow-up question (2b) –i.e. $[W_{ejk}^{ic}, W_{ejk}^{yc}]$.

The probabilities Pr(.) are modeled as arising from an extreme value distribution –which is the underlying distribution of a logit model. Because yields cannot be smaller than zero, we adjust the distribution to be zero-truncated. Also, we truncate the distribution from above because, arguably, there is a limit to the yields that can be observed in the local social-ecological systems in the Bolivian Altiplano. The maximum yields have been set at 20 –which is close to the maximum reported by experts under a wet climate change scenario (19.5 tons/ha). Details about the functional form of a truncated extreme value distribution are provided by Xu et al. (1994) who model, in a similar fashion than us, ranch land prices.

4. Summary of Experts' Opinions

The statistical approach described in Section 3.2 allows us to infer potato yields, conditioning on the factors described in the elicitation scenarios. We want to underline the following point: the conditional yields reported in this section correspond to those that experts judge feasible under the scenarios presented in the elicitation protocol. More specifically, the results in this section should not be interpreted as characterizing or modeling or defining the state of the potato yields in the Bolivian Altiplano.[3] Instead, the yields reported in this section reflect a summary of the opinions that experts have provided when requested to consider the specific conditions described in the elicitation scenarios.

4.1. Conditional Yields

Table 6 reports the conditional yields implicit in the experts' dichotomous answers. We present two sets of conditional yields. The first set is obtained from an Ordinal Least Squares (OLS) specification. The second set is obtained from maximizing the likelihood function described in Section 3.2. Presenting results from an OLS specification is a common strategy in the contingent valuation literature to check for consistency of the results delivered by the maximization of a likelihood function –e.g. Madani et al. (2013) and Cooper and Signorello (2008).

Both statistical models are informed with 248 observations, gathered from 12 experts –8 experts provided 24 answers; 3 experts provided 16 answers; and 1 expert provided 8 answers.

The dependent variable in the OLS specification corresponds to the yields implicit in the follow-up elicitation questions. Specifically, yields are assigned as follows: i) zero if the expert answered the sequence no-no to the elicitation questions; ii) the yields implicit in question (1) if the expert answered yes-no; iii) the yields implicit in question (2a) if the expert answered no-yes; and iv) the yields implicit in question (2b) if the expert answered yes-yes.

In both specifications, yields are conditioned on i) the community under analysis –i.e. we obtain average yields for each community—; ii) irrigation scenarios –via dichotomous variables defining whether the expert has answered to a no irrigation scenario or to an irrigation scenario; iii) climate change scenarios –via dichotomous variables identifying whether the scenario is dry observed (DO), wet observed (WO), dry climate change (DCC), or wet climate change (WCC)—; iv) two sets of interaction variables resulting from interacting the climate change scenarios and the community identifiers, and the irrigation scenarios and the community identifiers; and v) an heuristic factor –via a dichotomous variable identifying whether the expert is affiliated to a NGO.

[2] A double-bounded dichotomous question seeks to establish the range in which an individual's willingness to pay (WTP) falls. It does so by sequentially evaluating whether the WTP is larger or smaller than two values randomly assigned to respondents (Hanemann et al., 1991). The second value is chosen by the enumerator conditional on the answer to the first value –i.e. if the first response is "yes", the second value is larger; if the first response is "no", the second value is smaller.

[3] We thank the anonymous reviewer who pointed the need to clarify this point.

Table 6
Conditional yields.

Conditioning factors	Ordinal Least Squares (OLS)[a]		Maximum likelihood[b]	
	Conditional yields	Standard errors	Conditional yields	Standard errors
Communities[c]				
Intercept	2.56	(0.63)***	3.24	(0.44)***
Suriri-Capiri (SC)	2.01	(1.58)	1.14	(0.63)*
Pasacunta-Qollpacanta (PQ)	−0.75	(1.24)	−1.89	(0.65)***
Irrigation scenarios[d]				
Irrigation technology	3.25	(0.58)***	3.55	(0.31)***
Precipitation/temperature scenarios[e]				
Wet climate change (WCC)	2.15	(1.14)**	2.12	(0.67)***
Dry climate Change (DCC)	0.34	(0.71)	0.43	(0.63)
Wet observed (WO)	−0.61	(0.86)	−0.57	(0.66)
Interactions				
WCC * SC	−1.15	(1.31)	−1.24	(0.95)**
WCC * PQ	0.52	(1.02)	1.78	(0.97)**
DCC * SC	−1.89	(0.96)*	−2.30	(0.91)***
DCC * PQ	−0.51	(1.02)	0.61	(0.95)
WO * SC	−2.42	(1.63)	−2.36	(1.01)***
WO * PQ	0.87	(1.44)	2.94	(1.01)***
Irrigation * SC	−0.99	(0.99)	−0.23	(0.63)
Irrigation * PQ	1.58	(1.05)	0.97	(0.54)*
Heuristics				
Expert is affiliated to a NGO	5.66	(1.06)***	6.72	(0.44)***
R-squared	0.401		–	
Log-likelihood	–		−488	
Number of observations[f]	248			
Number of experts[f]	12			

Standard errors are clustered by expert.
Significant at *90% confidence level, **95% confidence level, and ***99% confidence level.
[a] For the OLS specification, the dependent variable is potato yields assigned as follows: zero if the expert answered no-no; the yields implicit in question (1) if expert answered yes-no; the yields implicit in question (2a) if expert answered no-yes; and the yields implicit in question (2b) if expert answered yes-yes.
[b] Likelihood function, as explained in Section 3.2, is truncated from below at zero and from above at 20.
[c] Reference category: Peñas Kerani scenario.
[d] Reference category: no irrigation scenario.
[e] Reference category: dry observed scenario.
[f] 8 experts provided 24 answers; 3 experts provided 16 answers; and 1 expert provided 8 answers, for a total of 248 observations.

The first set of conditional yields in Table 6 is estimated using the OLS specification. The first row reports the intercept parameter which reflects the average yields in Peñas Kerani –i.e. 2.56 tons/ha. The second and third rows report the yields specific to the other two communities –but the lack of statistical significance implies that, according to the OLS specification, yields do not significantly differ across communities. The next significant parameter in Table 6 captures the effect from the presence of an irrigation technique –an average increase of 3.25 tons/ha across communities. In terms of the potential impacts from climate change scenarios, experts expect that the WCC conditions increase yields by 2.15 tons/ha; and only Suriri-Capiri is expected to be impacted negatively by the DCC conditions –with a decrease of 1.89 tons/ha. The statistical significance of the variable identifying the NGO experts is interpreted as evidence of heuristic bias –i.e. NGO experts tend to report yields that are 5.66 tons/ha higher than the yields reported by other experts.

The second set of conditional yields in Table 6 result from maximizing the likelihood function in Section 3.2. The coefficients that are statistically significant in the OLS specification remain significant in the maximum likelihood (ML) approach, with identical signs but different point values. That is, average yields in Peñas Kerani are 3.24 instead of 2.56; the average increase due to irrigation is 3.55 instead of 3.25; the average increase due to WCC conditions is 2.12 instead of 2.15; the impact from the DCC on Suriri-Capiri is −2.30 instead of −1.89; and the heuristic bias is 6.72 instead of 5.66. This similarity in results is interpreted as evidence of consistency of the estimates.

Several factors that are not statistically significant in the OLS specification become significant in the ML approach –due mostly to a decrease in the standard errors which is an advantage from using the double-dichotomous methodology (Hanemann et al., 1991).

Thus, the ML approach allows us to gain further insights into the heterogeneity in the expected effects from climate change. For instance, in contrast to the OLS, the ML approach delivers differences in the average yields across communities. Importantly, we learn that experts consider that average yields are the lowest in Pasacunta-Qollpacanta –1.89 tons/-ha less than the 3.24 tons/ha in Peñas Kerani. Also, Suriri-Capiri is the community with the highest average yields in the opinion of the experts –1.14 tons/ha more than the 3.24 tons/ha in Peñas Kerani.

4.2. Impacts From Climate Change

The ML approach delivers insights into the experts' opinions about the direction and heterogeneity of climate change impacts at the local scale. Consistently with the OLS analysis, the ML approach documents that experts expect positive impacts from the WCC conditions. In addition, the ML approach delivers differences in the impacts from WCC across communities. For instance, while the effect from WCC conditions is expected to be 2.12 tons/ha in Peñas Kerani, this same positive effect is expected to be of only (2.12 − 1.24 =) 0.88 tons/ha in Suriri-Capiri. In contrast, WCC conditions are expected to increase yields by 3.90 tons/ha in Pasacunta-Qollpacanta. Thus, the positive impact from wet hypothetical conditions is expected to be largest at Pasacunta-Qollpacanta and smallest at Suriri-Capiri.

With respect to the effects from WO conditions, experts expect a negative effect in Suriri-Capiri (−2.36), a positive effect in Pasacunta-Qollpacanta (2.94), and no effect in Peñas Kerani. Thus, according to experts' opinions, wet observed conditions have impacted positively Pasacunta-Qollpacanta but negatively Suriri-Capiri.

Notice the consistency of the raking implied under both wet scenarios: Pasacunta-Qollpacanta is expected to benefit from wet climate change conditions; Peñas Kerani is expected to benefit moderately or not at all from wet conditions; and Suriri-Capiri may benefit but also may be damaged by wet climate change conditions.

With respect to the effects from DCC conditions, experts expect negative impacts on yields only in Suriri-Capiri (−2.30 tons/ha). Thus, Suriri-Capiri is not only expected to be damaged by wet climate change conditions buy also by dry ones.

4.3. Are Positive Effects From Irrigation Enough to Mitigate the Negative Effects From Climate Change?

The OLS and the ML approach deliver similar average positive impacts from irrigation across communities –an increase of 3.25 tons/ha (OLS) or 3.55 tons/ha (ML). And only the ML approach deliver a community-specific impact from irrigation –an increase of 0.97 tons/ha (additional to the average impact of 3.55 tons/ha) in Pasacunta-Qollpacanta.

We explore whether these positive effects from irrigation are enough to mitigate the negative impacts from climate change –i.e. whether experts expect that a community with irrigation and under climate change conditions will keep average yields at no irrigation, no climate change average levels.

Thus, we calculate potato yields under the four climate change scenarios and assume that an irrigation technique is in place. We also calculate the 95% confidence intervals because we want to check whether these conditional yields are different from average yields in a baseline scenario.[4] We choose the no irrigation, no climate change

[4] Conditional yields and their corresponding empirical 95% confidence intervals are estimated by taking 5000 Krinsky-Robb draws from a multivariate normal distribution. The vector of means and the covariance matrix of this multivariate distribution correspond to the coefficients reported in Table 6 for the ML approach and their corresponding covariance matrix (see Krinsky and Robb (1986) for details).

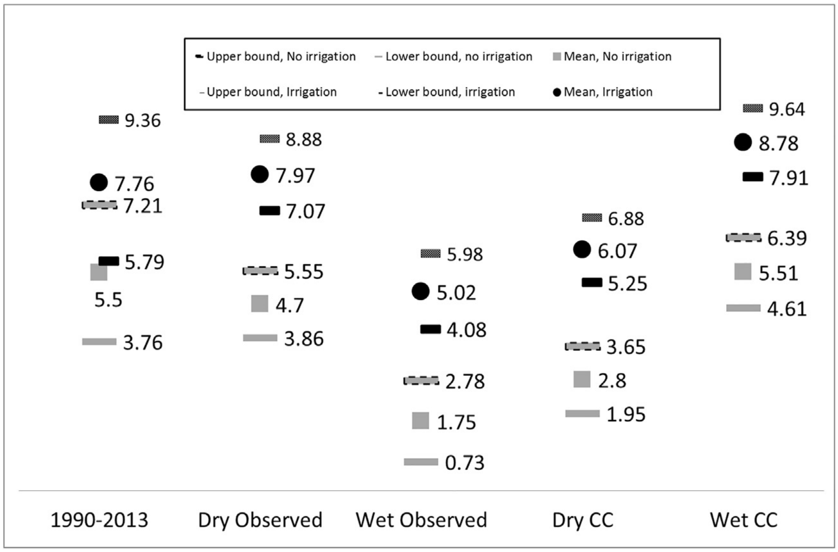

Fig. 3. Average yields (tons/ha) in Suriri-Capiri and 95% confidence interval by irrigation and climate change scenarios.

situation as baseline. Yields under this baseline scenario are inferred from experts' answers to no irrigation conditions and the average weather conditions presented in steps 1 and 2 of the elicitation procedure (see Fig. 2).

Importantly, when estimating these conditional yields, we assume that the dichotomous variable identifying the NGO experts takes value zero –i.e. we do not include in our estimations the extra yields that ONG experts tend to expect. This decision is discussed in Section 5.4.

Figs. 3 to 5 depict average yields and 95% confidence intervals. The grey symbols refer to the average yields (square), and lower and upper bounds (horizontal bars) under no irrigation scenarios. The black symbols refer to the average yields (circle), and lower and upper bounds (horizontal bars) under irrigation scenarios. From left to right, the first set of results refers to the 1990–2013 weather conditions presented as average to the experts. The other four sets of results refer, respectively, to the DO, WO, DCC and WCC scenarios.

Fig. 3 depicts results for Suriri-Capiri –which, according to the analysis in Section 4.2, may benefit or may be damaged by climate change. The baseline average yields in Suriri-Capiri are 5.5 tons/ha, with a 95% confidence interval ranging from 3.76 to 7.21.

For the DO conditions, Fig. 3 depicts a situation in which stoned-lines channels may not be the most effective irrigation technique to significantly boost yields. On one hand, DO conditions are not expected to dramatically impact yields —if Suriri-Capiri faces the DO conditions, experts judge that yields will fall within the 3.86 and 5.55 interval which is a statistically insignificant reduction with respect to the baseline yields. On the other hand, if stoned-lines channels are present under DO conditions, the extra yields are not enough to surpass baseline levels –experts judge that yields will fall within the 7.07 and 8.88 interval which mostly fall above the upper bound of the baseline yields but is still not enough to produce a statistical difference.

For the WO conditions, Fig. 3 depicts a situation in which stoned-lines channels represent an effective measure to mitigate the impacts from wet climate change conditions. On one hand, WO conditions are expected to drive yields below baseline levels if no irrigation is in place –falling between 0.73 and 2.78 which represents a reduction in yields with respect to the baseline values (3.76 to 7.21). On the other hand, if stoned-lines channels are present under WO conditions, the extra yields expected to fall between within 4.08 and 5.98 –range that falls within the 95% confidence interval of the baseline yields. That is,

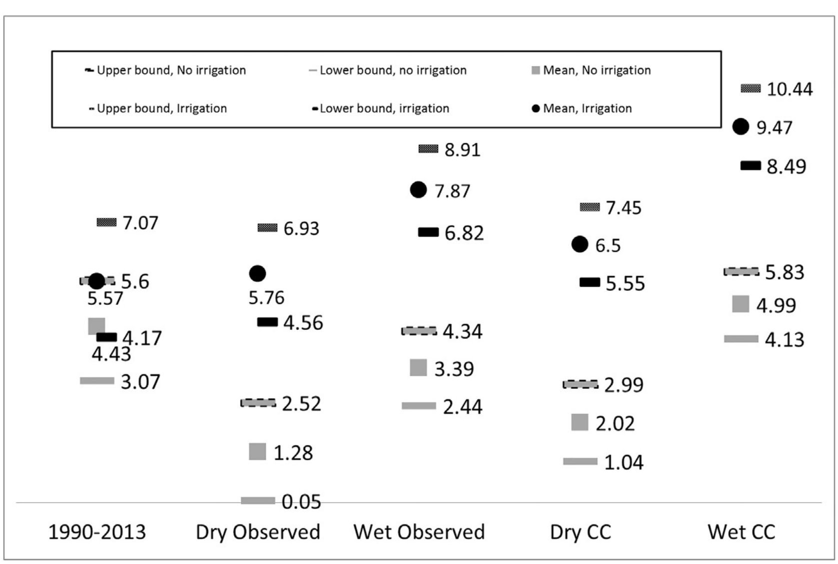

Fig. 4. Average yields (tons/ha) in Pasacunta-Qollpacanta and 95% confidence interval by irrigation and climate change scenarios.

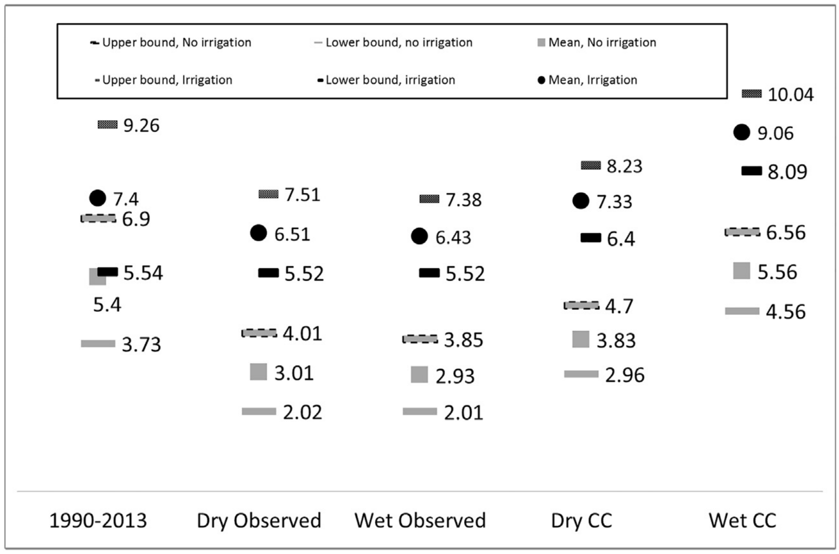

Fig. 5. Average yields (tons/ha) in Peñas Kerani and 95% confidence interval by irrigation and climate change scenarios.

yields under WO conditions are expected to fall below baseline yields, and stoned-lines channels are expected to return yields to values similar to those in the baseline scenario.

Following a similar reasoning for the DCC, Fig. 3 also illustrates that stoned-lines channels represent an effective mitigation tool under DCC conditions. For the case of WCC conditions, while the stoned-lines channels are effective at boosting yields, the WCC conditions are not expected to impact yields. This situation opens space to argue that, if no impact from climate change is expected under WCC, then irrigation techniques are not needed to mitigate climate change –argument that does not preclude the improvement of irrigation techniques for productivity purposes.

Fig. 4 depicts results for Pasacunta-Qollpacanta –which, according to the analysis in Section 4.2, is expected to be benefited by wet climate change conditions. The baseline yields are 4.43 tons/ha with a 95% confidence interval ranging from 3.07 to 5.57.

Fig. 4 illustrates that stone-lines channels in Pasacunta-Qollpacanta are expected to be an effective mitigation tool under dry scenarios (DO and DCC) –yields are expected to fall below the 95% baseline confidence interval but irrigation returns yields to baseline levels. For the wet scenarios, Fig. 4 illustrates that yields may not be negatively impacted by wet scenarios and, consequently, irrigation techniques may not be needed for mitigation purposes Again, this does not exclude the possibility that irrigation may be a good strategy to boost productivity –which seems to be the case under both wet scenarios, as illustrated by Fig. 4.

Finally, Fig. 5 depicts results for Peñas Kerani –which, according to the analysis in Section 4.2, is expected to be moderately impacted by climate change conditions. The baseline yields are 5.40 tons/ha with a 95% confidence interval ranging from 3.73 to 6.90.

Fig. 5 illustrates that open channel irrigation is expected to be an effective mitigation tool in Peñas Kerani. Three climate change conditions (DOO, WOO, and DCC) are expected to have negative effects, and WCC is expected not have no effects on yields. Under the three scenarios provoking negative impacts, open channel irrigation is expected to increase yields to baseline values.

5. Methodological Discussion

In this section, we discuss methodological issues that are arise in expert elicitation studies. This discussion is particularly important to this study because the format of our elicitation question doses not follow the conventional strategy of asking experts to report their opinions in distributional terms.

5.1. Motivation for Our Elicitation Question

We first discuss the motivation to borrow the double-dichotomous choice elicitation question. One main challenge of expert elicitation is its reliance on individuals that are experts on a given field but are not necessarily proficient at expressing their opinions in distributional terms (Bosetti et al., 2016). Conventionally, experts report their opinions in terms of probability distributions (e.g. Al-Awadhi and Garthwaite, 2006; Denham and Mengersen, 2007; Gill and Walker, 2005). However, even experts that are familiar with the concept of probability may find difficult to express their opinions in probability terms (James et al., 2010).

Experts consulted in this study are not the exception. Our experts, although proficient in probability and statistics, did not feel comfortable expressing their opinions in the form of probability distributions. We first realized this when designing the pilot elicitation questions with the help of Agronomist Corina Apaza –who was hired to assist the research team in, among other tasks, the design of the elicitation questions. Then, a couple of conventional versions of the EE questions were piloted and explained to potential experts during the personal visits paid to them in January 2014 –six months in advance to the implementation of the protocol. It became clear that reporting opinions in distributional terms was not a straightforward task for our experts.

Recognizing the similarities between the contingent valuation studies and the expert elicitation applications, we decided to test the feasibility of borrowing the double-bounded dichotomous question from the contingent valuation literature (see Hanemann et al., 1991). Initially, we tested the possibility of evaluating the changes in yields directly –that is, presenting changes in tons/ha units. However, this strategy did not prove straightforward neither. Then, we arrived to the format that we use in this study: changes in yields using as pivot the experts' own expectation of yields in the baseline scenario.[5] Our research assistant and one expert answering a pilot reportedly found this elicitation format intuitive and easier.

Why is that experts find easier to answer in a dichotomous way to changes presented in percentage terms? We believe that there is a

[5] Readers familiar with design of discrete choice experiments may notice the similarity of our strategy and the pivot design implemented in the Stated Choice literature (see Hess and Rose, 2009).

simple reason: in their professional careers, our experts frequently communicate judgements about percentage changes in a dichotomous manner. For instance, given a local social-ecological system, our experts recurrently judge whether an extra kg/ha of fertilizer may increase crop yields by 10%. They may also be able to judge whether an extra kg/ha increases yields by 1 ton/ha. However, they prefer to use a reference point in their judgement –e.g. last season's yields. A reference point helps because, among other things, the relations we are talking about are not linear. Economists are not unfamiliar with this situation –e.g. an economist may feel more comfortable providing opinions about price elasticities than about unitary changes in prices.

5.2. Cognitive Heuristics and Bias

We have argued in Section 5.1 that our elicitation question is advantageous because it is intuitive to our experts –resembling decision situations that they recurrently face. However, this elicitation format has implications in terms of anchoring.

It has been documented that, when people are presented to a starting value that they are asked to adjust, they typically do not adjust sufficiently –a cognitive heuristic known as anchoring (Morgan, 2014). If we were eliciting probability distributions, a standard procedure to minimize the influence of this heuristic is to ask first for the tails of the distributions.

But we are not directly gathering probability distributions. Instead, we are requesting that the experts adjust yields taking as reference value their own expectations on yields under average conditions. Thus, we may be inducing experts to anchor their expectations at their baseline yields.

We argue that anchoring is not a troublesome feature in this application. This is so because we are not interested on values falling in the tails of the yields' distribution. While we study the impacts of climate change, we have designed climate change scenarios that do not belong to the tails of the distribution of the climatic events –two scenarios have actually occurred in recent years. Consequently, impacts on the yields are not expected to fall in the tails of the distribution of yields.[6]

An additional cognitive heuristic, known as availability, implies that people assess the probability of an event by the ease with which examples can be brought to mind (Morgan, 2014). The usual strategy to minimize the chance of availability impacting experts' opinions is to encourage experts to systematically consider all relevant evidence. During the implementation of our protocol, experts were encouraged to exchange points of view during the first section of the workshop –during which experts were provided with the goal of the elicitation and background information. Then, experts were encouraged to answer the protocol taking into consideration what had been discussed but without consulting to each other during the last 2 h of the workshop.

5.3. Overconfidence

Overconfidence is pervasive in expert elicitation studies (Morgan, 2014). Overconfidence implies that experts state probability intervals that are poorly calibrated in the sense that they are too narrow –i.e. the realized value falls outside the central intervals much more frequently than they should (Bosetti et al., 2016).

We argue that the format of our elicitation question takes the burden of overconfidence away from the expert and put it on the researcher. This is so because the maximum length of the tails of the distributions are implicitly defined when deciding the percentage changes presented to the experts. As listed in Table 5, we aim to cover long tails by allowing not only for damages but also benefits from climate change. So, for instance, we asked experts if they would expect an increase of 60% in the yields under wet climate change scenarios.

The fact that the researcher implicitly decides the length of the tails of the distribution can be seen as a drawback. However, as with the anchoring issue, we argue that this application is less interested on the tails of the distributions and more on the central values.

5.4. Aggregation and Weighting of Experts' Opinions

We now discuss aggregation of expert's opinions –an issue that concerns to the analysis and presentation of the data gathered via an expert elicitation (Bosetti et al., 2016). Aggregation is attained either through mathematical strategies, or through a behavioral approach in which experts are requested to reach an agreement regarding the final values (Bolger and Rowe, 2015; Riabacke et al., 2012). The main motivation to aggregate experts' opinions is to inform policy makers (Bolger and Rowe, 2015).

Regardless the type of aggregation, a controversial issue is whether judgements of all experts should be weighted equally or not (Bolger and Rowe, 2015). Partially due to the controversy of weighting, some practitioners have proposed that documenting the heterogeneity in the experts' opinions is more informative than aggregated numbers (Morgan, 2014; Winkler, 2015). They argue that, because aggregation may hide the richness in opinions, heterogeneity in itself is relevant information for policy makers.

In this application we do aggregate but also document, to some extent, the heterogeneity in opinions –both across experts and across communities under study. Indeed, our aggregation approach is a mathematical one –explained in Section 3.2. We are able to document heterogeneity across experts because we identify that NGO experts tend to estimate higher yields than the other experts. We actually exclude these extra yields when estimating the values expected under climate change scenarios. By doing so, we are underweighting NGO experts. We do so because the aggregated numbers that we report are, arguably, useful to policy makers and we still can inform them about the heterogeneity in the opinions.

5.5. Is This an Expert Elicitation or a Contingent Valuation Applied to Experts?

We believe it is worth spending a few lines in the discussion of whether our application is an expert elicitation that borrows and adapts a question from the contingent valuation, or a contingent valuation study applied to experts.

We argue that the objective nature of the elicited quantity is the feature that makes this study an expert elicitation. That is, this study gathers subjective opinions from experts about the realization of an objective quantity (yields). A contingent valuation study, in contrast, gathers the subjective evaluation of an individual about a subjective quantity (willingness to pay).

A second reason to deem this study as an expert elicitation application is that experts' are familiar with the type of judgements we are requesting from them. They may not be used to communicate them through a protocol but they do recurrently carry out judgements about yields and their association with weather conditions. In contrast, respondents of a contingent valuation study are put under a scenario that is foreign to them –because contingent valuation is usually a last resource to simulate a non-existent market.[7]

[6] There are examples of previous applications that trade anchoring for simplicity. For instance, Landeta (2006) gathers the judgement of experts about tourist expenditures in Catalonia. This application, like ours, is mostly interested on the distribution around the average values than on the tails of the distribution. The tails would provide information about expenditures of outliers. But, in the context analyzed by Landeta (2006), information about the tails is less useful than a robust estimation of average tourist expenditures.

[7] We would like to direct the attention of the reader to a nascent literature that combines expert elicitation and non-market valuation: Leon et al. (2003), Alberinni et al. (2006), Van Houtven et al. (2014), Ahtiainen and Martinez-Cruz (2016), and Strand et al. (2017). Our study somehow relates to this literature, in the sense that intersections between expert elicitation and non-market valuation are explored. However, the topics of analysis of these papers, with the exception of Alberinni et al. (2006), do not directly relate to ours.

6. Conclusions

This paper explores whether expert elicitation is a useful tool to gain insights about impacts from climate change on crop yields in local social-ecological systems –for which good quality information is seldom available. In addition, we explore whether our data provide insights on the effectiveness of irrigation in mitigating the negative impacts from climate change.

In particular, we have gathered the opinions of experts about the impact from climate change on potato yields in three communities located in the Bolivian Altiplano. These communities are Suriri-Capiri, Pasacunta-Qollpacanta, and Peñas Kerani. We request from experts their judgements about the yields that would hold under four precipitation/temperature scenarios. These scenarios have been designed to resemble climate change conditions discussed in two documents: an *official* Bolivian document, and a report from the World Bank on the impacts from climate change in Bolivia. While these scenarios are not labeled when presented to the experts, we label them here as wet and dry –two of each type.

Our data allow us to document local heterogeneity in the climate change impacts expected by experts. In average, wet climate change scenarios are expected to positively impact yields, and dry climate change scenarios are expected to decrease yields. However, these average effects hide substantial heterogeneity across the communities under study. For instance, Pasacunta-Qollpacanta is expected to benefit from wet climate change conditions; Suriri-Capiri may benefit or may be damaged by wet climate change scenarios; and Peñas Kerani is expected to not be impacted by wet conditions. In contrast, only Suriri-Capiri is expected to experience losses under dry climate chance scenarios, and the other two communities are expected to experience no changes at all.

Our data also allow us to document heterogeneity in the expected effectiveness of irrigation as a mitigation tool. Effectiveness varies not only across communities but also across climate change scenarios. For instance, under dry scenarios, irrigation is clearly effective in Pasacunta Qollpacanta but not so in Suriri-Capiri.

This study is ultimately motivated by the need to inform public policies with the best available scientific knowledge. Indeed, our study delivers helpful insights for policy makers in Bolivia. On one hand, our results suggest that irrigation is an effective tool to mitigate the effects from dry climate change scenarios. On the other hand, because wet scenarios may benefit at least one of these communities, policy makers may want to reconsider the encouragement of irrigation for mitigation purposes in this community –which does not exclude the possibility that policy makers finance irrigation projects for productivity reasons. Clearly identifying the purpose of a policy is essential to implement evidence-based policies –which in this case implies that policy makers are informed that irrigation may not be needed for mitigation purposes but for productivity ones.[8]

A caveat is in place. Given our data gathering strategy, the results of this paper cannot be interpreted as characterizing or defining the state of the potato yields in the Bolivian Altiplano. Our results aggregate the most informed judgements about how yields react to the specific conditions described in the elicitation scenarios. The elicitation scenarios capture realistic features but, by design, remain simple and manageable. Thus, as with any other model that simplifies reality, our results hold within the limits of the scenarios defined in our elicitation procedure, and generalizations are not recommendable.

Despite this caveat, we believe that our data collection strategy represents a promising decision support tool for a wide range of public policy issues. Particularly, when monetary and time constraints converge with the lack of scientific information. For instance, State authorities in Mexico usually have less than three months to select the municipalities that should be covered by a government-sponsored index insurance. Indeed, these decisions have been taken in the absence of a strategy to gather local data (see Martinez-Cruz et al., 2016). A second example refers to the gathering of information about overuse of watersheds. In this context, authorities may be interested in learning which strategies are expected to contribute the most to preserve a watershed. A straightforward way to adapt this paper's methodology is as follows: in the first round of questions, ask the experts for their judgement of the gap between supply and demand of water in the watershed –this question is pertinent because there is usually uncertainty about the magnitude of this gap. Then the elicitation questions would refer to percentage changes in the gap due associated with specific water conservation strategies.[9]

Our data collection strategy represents an alternative to incorporate the opinions from experts into methodologies that also gather local information –e.g. participatory strategies (Bentley Brymer et al., 2016) and citizen science methods (Bonney et al., 2009). For instance, Van Aalst et al. (2008) explore the use of community risk assessment in the context of climate change adaptation. Our methodology could complement a participatory study with similar goals than Van Aalst et al.'s (2008) by suggesting risk management instruments that have been pre-selected based on experts' opinions and need to be adapted to local governances.

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[8] Indeed, this argumentation points to a related but different research topic: underlying this argument, we are assuming that policy makers can assign probabilities to the occurrence of a given climate change scenario. This is hardly the case and opens the possibility of eliciting probabilities of occurrences of local climate change scenarios.

[9] Ongoing work on this issue is being carried out by Sainz-Santamaria and Martinez-Cruz (2017).

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